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SimTerm2022 PROCEEDINGS

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ENERGY EFFICIENCY ECONOMY ECOLOGY

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Composting system's reliability in controlled conditions of the high-temperature waste treatment

Milica Ivanović [a], Miroslav Mijajlović [b], Dušan Ćirić[b], Filip Pešić[b], Gordana Jović[c]

[a] Academy of Applied Technical Studies Belgrade - Applied engineering sciences Požarevac, Požarevac, RS, milica.ivanoviic@gmail.com
[b] Faculty of Mechanical Engineering, University of Niš, Niš, RS, miroslav.mijajlovic@masfak.ni.ac.rs
[b] Faculty of Mechanical Engineering, University of Niš, Niš, RS, dusan.ciric@hotmail.com,
[b] Faculty of Mechanical Engineering, University of Niš, Niš, RS, filipvego@yahoo.co.u
[c] Academy of Applied Technical and Preschool Studies - Department of Niš, Niš, RS gordana.jovic@akademijanis.edu.rs

Abstract: Composting is a good way to solve the problem of organic waste (OW) and therefore, it is widely used. It can take place outdoors under partially controlled conditions and in reactors under well-defined conditions. The composting system in reactors is a complex unit and serves to keep parameters such as temperature, aeration, moisture, and oxygen content within the optimal range for the process. Controlling these parameters allows for faster carry-out processes and shorter process times. However, due to the presence of sensors to control parameters such as temperature, moisture content, and oxygen, this system is quite sensitive, which can failure of some elements, and that can be reflected in slowing down the process and, ultimately, the quality of the product. Failures of certain system elements can be due to malfunction or damage that may occur during the treatment of various types of OW. This paper shows the estimation of the composting system's reliability under controlled conditions in the reactor. This paper aims to determine the reliability of reactor composting systems from the aspect of expanding their use.

Keywords: reliability, failure, waste treatment, composting

1. Introduction

Composting is the second most used biological treatment in which organic matter is transformed into a stable compound - compost by using microorganisms [1]. The composting process can be used to treat different types of organic waste: organic fractions of municipal, agricultural waste, animal manure and organic waste from industry. The advantage of this treatment is that the obtained compost can be used as an organic fertilizer, which enables the return of nutrients to the soil.

Many factors affect the composting process, such as C/N ratio, pH value, moisture content, particle size, presence of easily degradable components, and temperature - whether the process is carried out under controlled conditions or not [2]. Parameters such as C/N, pH value and content of easily degradable compounds depend on the type of OW and are achieved by mixing different types of OW. Moisture content, aeration and temperature are factors that can be controlled using certain devices. The composting process can be carried out outdoors or indoors, which are the so-called composting systems. Composting systems can be divided into two groups: open and closed systems, with the help of which it is possible to wholly or partially control the process of OW construction. Open systems are the so-called "on situ" systems with active and passive aeration [3][4]. Open systems are widely used due to low investment and operating costs as well as simple construction. The basic construction can contain additional elements for aeration - aerated systems or not - passive. However, although these systems are effective, it has been shown that the main disadvantages are the long duration of the process, the inhomogeneity of the mass and the complex control of the conditions due to external factors [5][6]. Aerated systems emit significant NO3 gas emissions, which is another unfavourable influence of parameters in outdoor composting [7].

In the case where it is desired to speed up the process and achieve specific parameters, composting is performed in closed systems that can be horizontal or vertical, depending on the supply of raw materials in the reactor. Closed systems for composting, so-called in-vessel systems, are used for laboratory process monitoring (pilot scale) and practical use (full scale) when treating large amounts of OW [8]. Laboratory systems have a small volume (10l) and are used for monitoring the decomposition of individual types of OW, optimization and parameter definition during process modelling [9]. Full-scale systems are practically used for the treatment of various types of OW, and their volume ranges from ten to several thousand liters. With closed systems, parameters such as temperature, air and moisture content can be controlled, which results in a faster process. In larger systems, due to the self-heating of the mass, the temperature exceeds 60℃ [10]. However, as the composting process takes place in several stages if temperature changes are observed, heaters are often installed in the system, which are used to heat the mass at the beginning of the process to achieve higher temperatures. In this way, the process is additionally accelerated, and, at the same time, pathogenic organisms are destroyed, thus meeting ecological standards. The advantages of using closed systems are reflected in several factors (i) ecological-environmental conditions because there is no release of gases during the process, (ii) enabling the monitoring of parameters that affect the process and (iii) elimination of the heterogeneity of the treated mixture [11]. In most cases, these systems are automated and contain many elements that enable process control and monitoring and therefore require significant investment costs due to the equipment they have [12].

Reliability is defined as the ability of the object to fulfill the specified functions and maintain the value of the operating parameters over time within the specified limits, determined by the selected modes and conditions of use [13]. The theory of reliability is widely spread, especially in technology, in the design, testing, production and exploitation of technical products so that they have the most extended working life and thus the maximum performance. The primary factors present in the reliability theory are working time and working conditions because the data provided are valid only in the specified period and specific conditions of use [14]. In the last few years, the reliability theory has been applied in the development of waste management systems [15] and obtaining energy from renewable sources, which also include economic parameters [16] [17]. In this paper, a closed system for composting was discussed, which from a structural point of view, contains all the elements for complete control of the process, such as temperature, humidity, aeration and control of the gases that are emitted. In the first part of the paper, a description of the elements and a graphic representation of the considered composting system are given. Then, based on the layout of the elements and the application of the exponential distribution law, the system's reliability is calculated, which is the paper's goal.

2. Materials and methods

2.1 System description

Closed composting systems represent a unit or set of units in which the composting process takes place. As composting is a biological process, these units are also called bioreactors [18]. In this paper, the composting system considered is a complex one, Figure 1. As shown in Figure 1, the system consists of elements that can be used to control physical-chemical parameters, temperature, moisture and oxygen content, and control gases that are also released during the process by the shovels for turning over the compost mass. As the decomposition of OW takes place at elevated temperatures, and in order to reduce heat loss through the walls of the reactor, it was taken into account that the rector is lined with insulating material. In addition to the above, when considering the composting system, it was assumed that the treated mass is heated, that is, there is a heat source. Also, a system that is automated was considered.

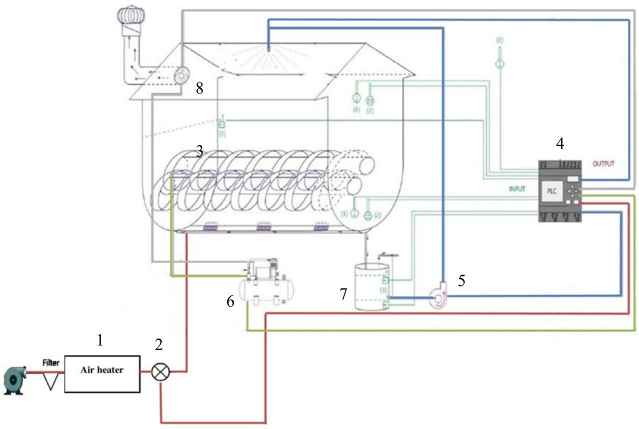

Figure1. Schematic representation of the composting system (Adopted from [18])
Air heater; 2. Valve; 3. Turning blades; 4. PLC; 5. Pump; 6. Electric motor; 7. Reservoir; 8. Fan.

The basic elements of the composting system, which are used to control the process, are an air filter, heater, valve, electric motor for starting the pile turning blades and fan, water pump, sensors that monitor temperature changes in the compost mass and outside, the water level in the tank and humidity in the compost mass, which is connected to the PLC, water tank.

Temperature - is monitored using sensors located at the bottom and the top of the compost mass in the reactor. The air is heated to the desired temperature using the heater (1) placed after the fan and filter in the system. The air supply to the compost mass is controlled by the valve (2) located after the heater and connected to the PLC (4). The heating of the compost mass is carried out using an aeration system, where heated air is introduced into the compost mass through the perforated floor in the reactor.

Moisture – is maintained by adding water. Water during the composting process was added using sprinklers located on top of the reactor. Water in the spray system is supplied using a pump (5) connected to a tank (7). In the tank, in addition to the water that is brought in from the side, the so-called "strained water" is separated during the composting process. Wet control is monitored using a sensor located at the bottom and the top of the compost mass; the water level in the tank (7) is also observed, and all these data are controlled using a PLC (4).

Oxygen content and aeration are closely related parameters that are monitored during the composting process. Aeration is performed in the observed system in two ways. The first way, aeration, takes place forcibly by blowing air into the mass (warm air), and the direction of the air is towards the top - from the bottom up through the reactor floor. Another way, turning the compost mass using turning blades (3) that are connected to the electric motor (6) and PLC (4). In this way, in addition to aeration, the compost mass is homogenized, which achieves uniform decomposition.

Control of exhaust gases - during the composting process, a significant amount of gases are released as a result of the decomposition of organic matter. In the observed system, the release of released gases was carried out using a fan (8) located at the top of the reactor and connected to the electric motor (6) and PLC (4).

3. Experimental design

3.1 Model forming

For the previously described composting system, reliability was determined based on the elements that make up the system. When determining the reliability, some assumptions were introduced: the exponential distribution is for all elements, the system was considered as irreparable - it works until failure, and the reliability of the elements changes over time, mainly under the influence of heat and mechanical damage. Several case studies have been observed depending on the assumptions of the failure of individual elements. In the first case, the system was observed when all considered elements were working. In the second case, it was observed when the minimum number of elements of the composting system are working, while in the third case, the system was observed when one or more elements are not working - they are on the verge of failure.

Case study 1

In the first case, it is assumed that all the elements that make up the composting system are working. The composting process proceeds smoothly, so maximum productivity is achieved with minimal time duration, Figure 2.

Figure2. Block diagram of case study 1

Case study 2

In the second case, a composting system was observed when the minimum number of elements is working. The composting system works if only element 3 (turning blades), element 6 (electric motor), element 7 (reservoir) and element 8 (fan) are working. In this case, the system functions with deteriorated characteristics (which are taken via the fictitious elementKf_1). In this case, the average composting time is long, and the productivity (effectiveness) of the system is minimal, Figure 3.

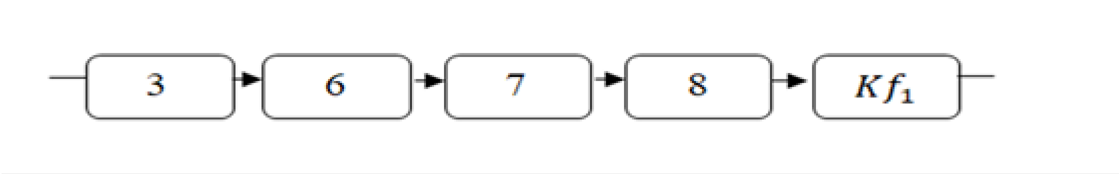

Figure3. Block diagram of case study 2

Due to the functioning of a minimal number of elements (blade (3), electric motor (6), tank (7) and fan (8)), the system is in minimal operation mode because the main elements are not working. The consequence of the failure of other elements is reflected in the course of decomposition of the compost mass inside the reactor, due to uncontrolled conditions - temperature and moisture content. As a result of this mode of operation, the quality of the obtained product is of questionable quality, provided that the process took place under the given conditions.

Case study 3

In the third case, it was observed that one element stopped working. Thus, by the failure of element 1, the composting system is brought to the hour of minimum functionality, even though all other elements are functioning.

In the case of failure of element 2 (valve), the composting system is in a state of reduced functionality - element 1 (water heater), although fully functional, does not perform its function fully but functions limitedly (which is taken through factor Kf_2).

Element 4 (PLC) also functions with deteriorated characteristics, which is taken through the factor Kf_3, Figure 4.

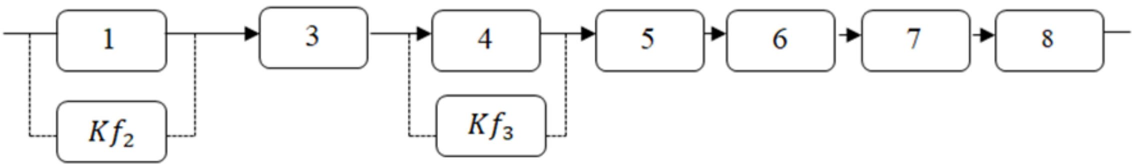

Figure4. Block diagram of case study 3

As a result of the failure of element 2 (valve), the system is not functional due to the impossibility of controlling the flow of heated air. The whole system is disturbed, so the duration of the process is shortened (too much heating of the mass), but with the deterioration of the quality of the obtained product.

In case of failure of element 3 (turning blades), there is a partial failure of the system - no execution of the basic function of the system. And with the failure of element 4 (PLC), the system is brought to a state of limited functionality: element 2 becomes redundant/unnecessary, and all others function with significant deterioration, Figure 5.

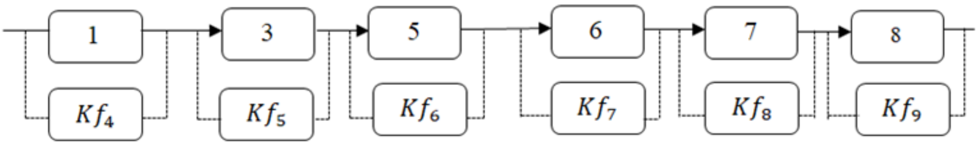

Figure5. Block diagram of case study 3

As aeration is essential for the composting process, in case of element 3 (blade) failure, aerobic conditions will appear inside the mass, while the surface of the mass will be dry. Also, with the failure of element 4 (PLC), the composting system is out of control - the basic parameters (temperature, humidity, aeration and amount of gases) cannot be monitored. This significantly straightens the process, so the decomposition time is extended.

Furthermore, if element 5 (pump) fails, the system is in a state of limited functionality, while elements 3 (blades) and 4 (PLC) function with degraded characteristics, Figure 6.

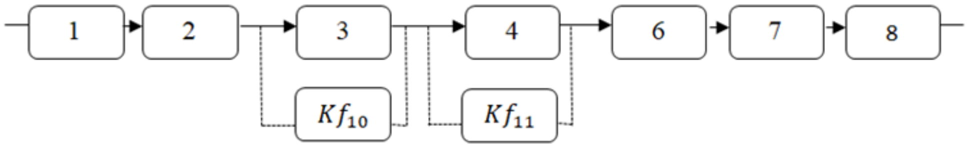

Figure6. Block diagram of case study 3

In this case, due to the lack of moisture, the compost mass dries out, which has the effect of slowing down or completely stopping the process.

Then, in case of failure of element 6 (electric motor), the system is in a state of limited functionality, while elements 3 (blades) and 4 (PLC) function with deteriorated characteristics, Figure 8.

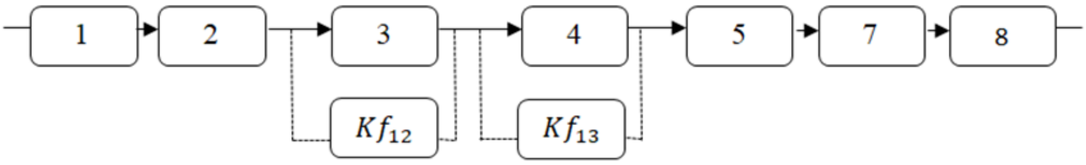

Figure7. Block diagram of case study 3

As element 6 is essential for starting elements 3 and 8, for controlling aeration and expelling released gases, its failure changes the course of the process. Anaerobic conditions appear inside the mass due to the cessation of turning of the mass, an increase in the temperature within the mass and the occurrence of drying of the mass on the surface of the pile. This significantly reduces the quality of the product, and the system is minimally functional.

In the case of element 7 (reservoir) failure, the system is in a state of forced failure - the system is functional but cannot continue due to the accumulation of excess liquid. While with the failure of element 8 (fan), the system is in a state of impending failure - the system is functional but must be shut down because there is an increase in temperature in the reactor. There is no removal of released gases, and the temperature rises, so the process is further slowed. The failure of this element requires a complete stop of the process because there is a risk of destroying the entire system.

3.2 Calculating the reliability of a given system

For the previously defined composting system, its reliability was calculated. The average working time and λ of individual elements are taken from the literature. Table 1 shows values for the average operating time of the entire system and individual elements.

When calculating the reliability for the average operating time of the entire system, it was taken as 100000h.

Table1. Mean operating time of system and elements

t = 100000h	λ_1[1/h]	λ_2[1/h]	λ_3[1/h]	λ_4[1/h]	λ_5[1/h]	λ_6[1/h]	λ_7[1/h]	λ_8[1/h]
	$5 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$4 \cdot 10^{-6}$	$1 \cdot 10^{-6}$	$8 \cdot 10^{-6}$	$1.4 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	$6 \cdot 10^{-6}$

Based on the average operating times of individual elements and the average active time of the composting system, their reliability was determined. During the calculation, the mean working times of intervals of t=20000h were also taken into consideration. Table 2 shows the obtained values for the reliability of individual elements when different intervals of the mean working time were considered.

Based on the obtained results shown in Table 2 for the reliability of individual elements of the composting system, a diagram is shown in Figure 8.

Table2. Reliability values of system elements

	4.00E+03	*t* = 20000	*t* = 40000	*t* = 60000	*t* = 80000	*t* = 100000
R1	0.980199	0.904837	0.818731	0.740818	0.67032	0.606531
R2	0.992032	0.960789	0.923116	0.88692	0.852144	0.818731
R3	0.984127	0.923116	0.852144	0.786628	0.726149	0.67032
R4	0.9996	0.998002	0.996008	0.994018	0.992032	0.99005
R5	0.968507	0.852144	0.726149	0.618783	0.527292	0.449329
R6	0.994416	0.972388	0.945539	0.919431	0.894044	0.869358
R7	0.992032	0.960789	0.923116	0.88692	0.852144	0.818731
R8	0.976286	0.88692	0.786628	0.697676	0.618783	0.548812

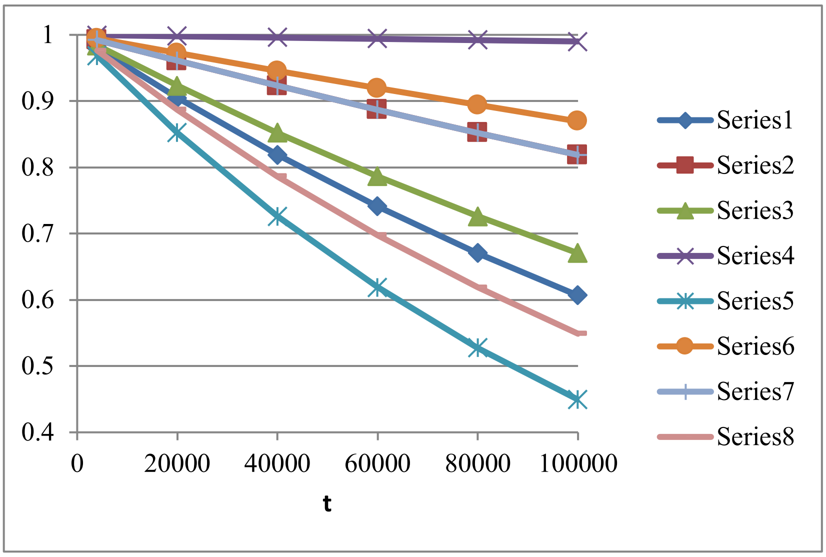

Figure8. Diagram of reliability function of individual elements

When determining the reliability of the entire composting system, a virtual model was created for the considered case studies. During the formation of the model, corrective factors K_f, were introduced, the values of which are different and depend on the assumed operating conditions of the entire system. The values of the correction factors K_f, are shown in table 3.

Table3. Values of correction factors K_f

	K_{f1}	K_{f2}	K_{f3}	K_{f4}	K_{f5}	K_{f6}	K_{f7}	K_{f8}	K_{f9}	K_{f10}	K_{f11}	K_{f12}	K_{f13}
K_f	0.1	0.2	0.15	0.5	0.2	0.2	0.2	0.2	0.2	0.05	0.1	0.15	0.2

Based on the adopted correction factors K_f , shown in Table 3, the reliability of the composting system was determined for all considered case studies. The average operating time of the system is 100000h. The system reliability values are shown in Figure 4.

Table4. Reliability of the system for the observed case studies

	Case study	4.00E+03	*t* = 20000	*t* = 40000	*t* = 60000	*t* = 80000	*t* = 100000
All elements work	C1	0.892258	0.565525	0.319819	0.180866	0.102284	0.057844
Minimal elements work	C2	0.094781	0.076491	0.058508	0.044754	0.034232	0.026185
Failure of element 1	C2	0.094781	0.076491	0.058508	0.044754	0.034232	0.026185
Failure of element 2	C3	0.027539	0.019554	0.012746	0.008308	0.005415	0.00353
Failure of element 3	C4	0	0	0	0	0	0
Failure of element 4	C5	0.00016	0.00016	0.00016	0.00016	0.00016	0.00016

Failure of element 5	C6	0.004683	0.003602	0.002595	0.001869	0.001346	0.00097
Failure of element 6	C7	0.027363	0.018939	0.011956	0.007547	0.004765	0.003008
Failure of element 2		0.892258	0.565525	0.319819	0.180866	0.102284	0.057844
Failure of element 8		0.892258	0.565525	0.319819	0.180866	0.102284	0.057844

Based on the obtained results shown in Table 4 for the reliability of the considered case studies, a diagram was formed, shown in Figure 9.

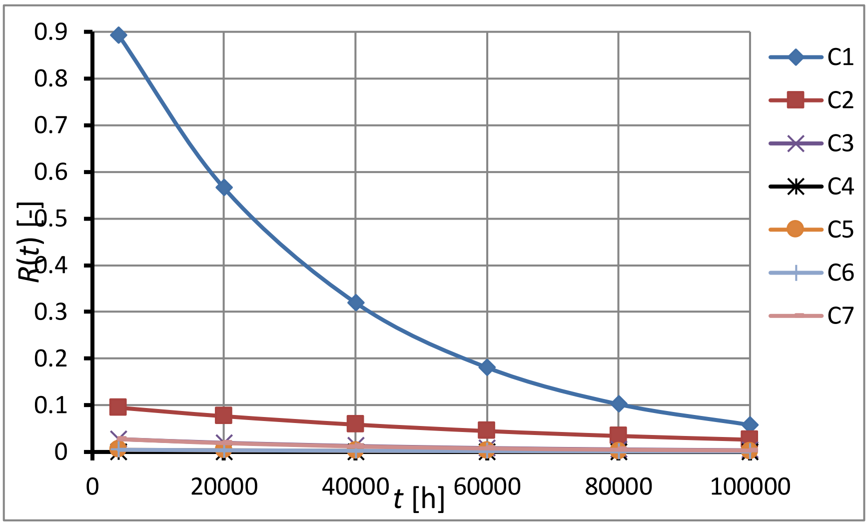

Figure9. Diagram of system reliability function

In the first case, when the reliability of individual elements was considered, based on the obtained results (Figure 9), it can be seen that it ranges from 0.45 to 0.99. The lowest reliability is shown by element 5 and the highest by element 4. It can also be seen from Figure 9 that the elements (1 and 5) that regulate the most important parameters of the process have a reliability of 0.60 and 0.45, which is low, that is, there is a greater chance that these elements fail. Other elements have a reliability of 0.54 to 0.86, indicating the possibility of failure during the observed time.

In the second case when the reliability of the whole system and the case study were considered, it can be seen from Figure 10 that the reliability is low. In the case when the system is observed when all the elements are working, the reliability ranges from 0.90 at the beginning to 0.057 at the end of the observed average operating time. If we look at the reliability of the case studies when the minimum number of elements is working, it can be seen from Figure 10 that the reliability is 0.261, so the probability that the system will fail is high. When the reliability of the system (case study 3) was observed from Figure 10 and Table 4, it can be seen that in the second case, when element 1 fails, the system has a reliability of 0.261, which is the same when the minimum number of elements is working. In other cases, the reliability is very low and ranges from 0 to 0.0035. Such low reliability indicates that the system is not functional if one of the elements does not work.

Conclusion

Reliability theory has a wide spread when considering different technical systems, considering that their complexity increases with age. In this paper, the reliability of the composting system was determined. The observed system is complex, consisting of eight elements that enable the composting process to proceed smoothly. When determining reliability, the reliability of individual elements was determined in the first step, and the reliability of the entire system in the second step, considering several case studies. Based on the obtained results, it can be seen that the reliability of individual elements is high, so the chances of failure are less. In the second case, based on the obtained results, it can be seen that the reliability is low, except in the case when all the elements work. This indicates that the system is not functional in case of failure of one of the elements or it functions minimally.

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